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Study of the correlation of diurnal growth patterns to climatic variables in a Salix energy plantation

Barbara J. Dowsley

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STUDY OF THE CORRELATION OF DIURNAL GROWTH PATTERNS TO CLIMATIC VARIABLES IN A *SALIX* ENERGY PLANTATION

by Barbara J. Dowsley

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ABSTRACT

This report examines the within season growth patterns of three Salix clones at the Newfoundland Forestry Research Centre's Nursery at Pasadena during the 1985 growing season. Salix viminalis clone 0683 proved to be the most successful cultivar in terms of final mean height and base diameter achievement. This was attributed to its ability to continue growth later in the season as compared to the other two clones. Daily maximum height growth in all three species occurred between 14:00 and 22:00 hours NDST (Newfoundland Daylight Saving Time). Daily maximum base diameter growth occurred between 22:00 and 06:00 hours NDST. Weekly climatic variables recorded at the study site are reported.

RÉSUMÉ

Sont examinées les caractéristiques de croissance au cours de la saison de 1985 de trois clones de Salix cultivés à la pépinière du Centre de foresterie de Terre-Neuve, à Pasadena. Le clone 0683 de Salix viminalis s'est révélé le meilleur cultivar en ce qui concerne la hauteur moyenne finale et le diamètre basal. Sa meilleure performance a été attribuée à la fin plus tardive de sa période de croissance par comparaison aux deux autres clones. L'accroissement journalier, pour les trois espèces, était maximal entre 14 et 22 h (heure avancée de Terre-Neuve) pour la hauteur et entre 22 et 6 h pour le diamètre basal. Les variables climatiques hebdomadaires enregistrées à l'emplacement d'étude sont présentées.

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1.0 INTRODUCTION

The field of agroforestry has received increased attention over the last decade. The Canadian Forestry Service (Newfoundland and Labrador Region) began research into the potential of *Salix* species as an agroforestry crop in 1981 (Robertson 1984b). Willows provide a high yield at an early age which makes them attractive as a short rotation crop with the potential of being harvested every two to three years. The CFS has collected approximately 180 *Salix* clones from Europe and eastern North America and preliminary screening of their performance was conducted at the CFS nursery at Pasadena, Newfoundland. It is hoped that plantations of willow might eventually be established on forest cutover areas, peatlands, heathlands, scrub forest and urban and agricultural areas throughout the Island (ibid). Potential uses of willow plantations include environmental improvement, biomass energy for liquid fuel, fodder supplement, chemicals and pulp (Robertson 1984a). The island of Newfoundland experiences wide climatic variation and it would therefore be advantageous to have insight into those meteorological variables that influence biomass production when determining potential sites for plantations.

2.0 OBJECTIVES

The project was designed with the following objectives:

1. To compare the performance and pattern of growth of three species of Salix clones in an energy plantation environment.
2. To determine the influence of the local climate on the above growth pattern by simultaneously monitoring meteorological variables at the study site.
3. To determine the diurnal pattern of growth of the three Salix species under investigation.

3.0 MATERIALS AND METHODS

The investigation took place during the 1985 growing season at the CFS nursery at Pasadena, Newfoundland (lat. 49°01', long. 57°36'). The nursery has willow clones planted at a density of 30 000 to 35 000 trees/ha. An area of the plantation was chosen where clones of Salix purpurea, S. viminalis and S. alba had been established in adjacent rows approximately 50 cm apart, with a spacing of 20 cm occurring between the plants. The three species had experienced two full seasons of growth prior to being cut to ground level on May 7, 1985. Thirty stools of each species clone were randomly selected on May 27 for examination throughout the growing season.

Height of the longest shoot on each of the 90 stools was measured to the nearest 0.5 cm with a standard tape measure and recorded on a weekly basis from June 10 to October 7. Diameter of the same shoot

at approximately 0.5 cm above where it emerged from the stool (henceforth referred to as basal diameter) was measured to the nearest 0.1 cm using Venier calipers and was also recorded on a weekly basis throughout the growing season. Height and basal diameter were recorded three times daily at 06:00, 14:00 and 22:00 NDST (Newfoundland Daylight Saving Time) from June 20 until August 22.

A Stevenson screen containing a Casella thermohygrograph, maximum and minimum thermometers, and wet and dry bulb thermometers were established at the edge of the plantation field where the species under investigation were located (see Figs. 1 and 2). Air temperature was recorded continuously throughout the growing season while maximum and minimum air temperature and wet and dry bulb temperatures were recorded at eight hour intervals from June 20 to August 22 and once weekly for the remainder of the study period. Cumulative heat units for the growing season were calculated from the start of bud break on May 22, using the following formula:

$$HU = \sum_{i=1}^{N} \left[\frac{T_a + T_b}{2} - T_t\right], \text{ when } \frac{T_a + T_b}{2} > T_t$$

where N is the number of days from bud break, T_a is the daily temperature maximum, T_b is the daily temperature minimum and T_t is the base temperature (6°C).

Figure 1. Experiment site and Stevenson screen.

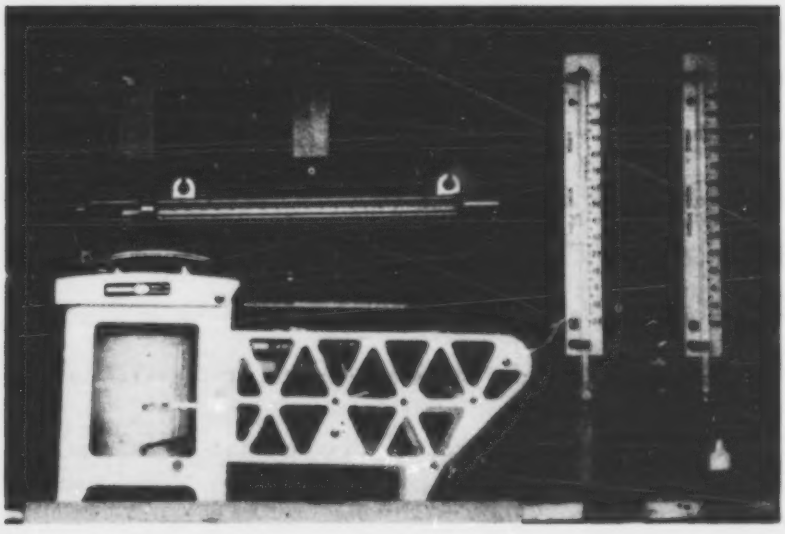

Figure 2. Contents of Stevenson screen.

Three YSI temperature probes were established in each of the three species rows at depths of 10, 20 and 30 cm below the soil surface. Instantaneous reading of temperature to the nearest 0.5°C were recorded via a YSI model 42SC tele-thermometer at eight hour intervals from June 20 until August 22.

Windspeed at 3.04 m above the ground and precipitation were monitored at a point approximately 10 m from the trees being studied, over a grass field. Windspeed was recorded continuously throughout the study period with a Science Associates anemometer (Fig. 3) and an Easterline-Angus recorder (Fig. 4). Weekly mean windspeed at 3.04 m was calculated from daily means determined from hourly observations taken from the Esterline-Angus recorder. Precipitation was measured by a daily check raingauge (Fig. 5) and recorded to the nearest 0.25 cm at eight hour intervals from June 20 until August 22 and once weekly for the remainder of the study period.

4.0 RESULTS

4.1 Seasonal Growth

The cumulative height growth for each of the three Salix species studies at Pasadena during the 1985 growing season is displayed in Figure 6. Cumulative heat units for the growing season are also displayed in the same figure. S. viminalis attained the greatest mean height by the end of the growing season ($\bar{x}$ = 208.5 cm, $S_{\bar{x}}$ = 4.0 cm)[1].

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[1] $\bar{x}$ mean $S_{\bar{x}}$ = standard error of the mean.

Figure 3. Science Associate's anemometer.

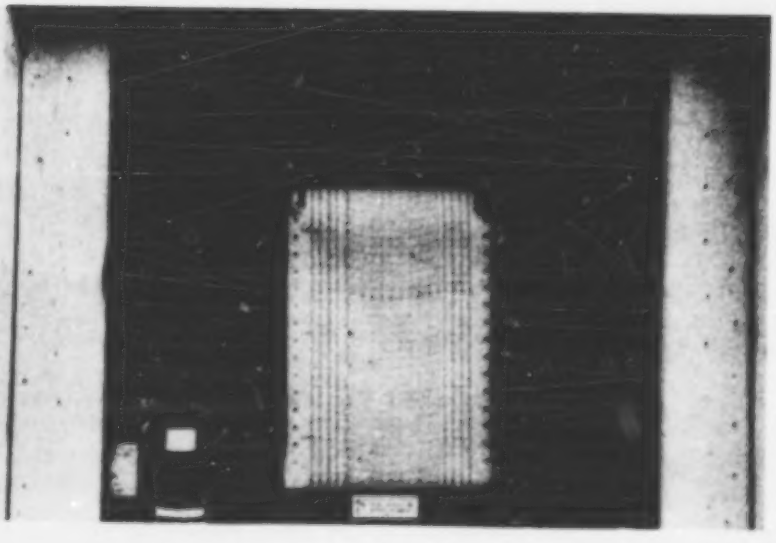

Figure 4. Esterline-Angus recorder.

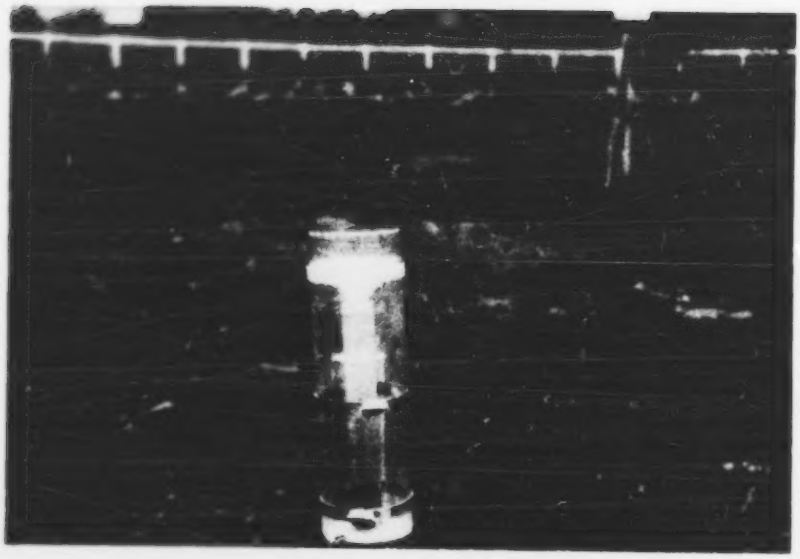

Figure 5. Manual Clear-Vu raingauge.

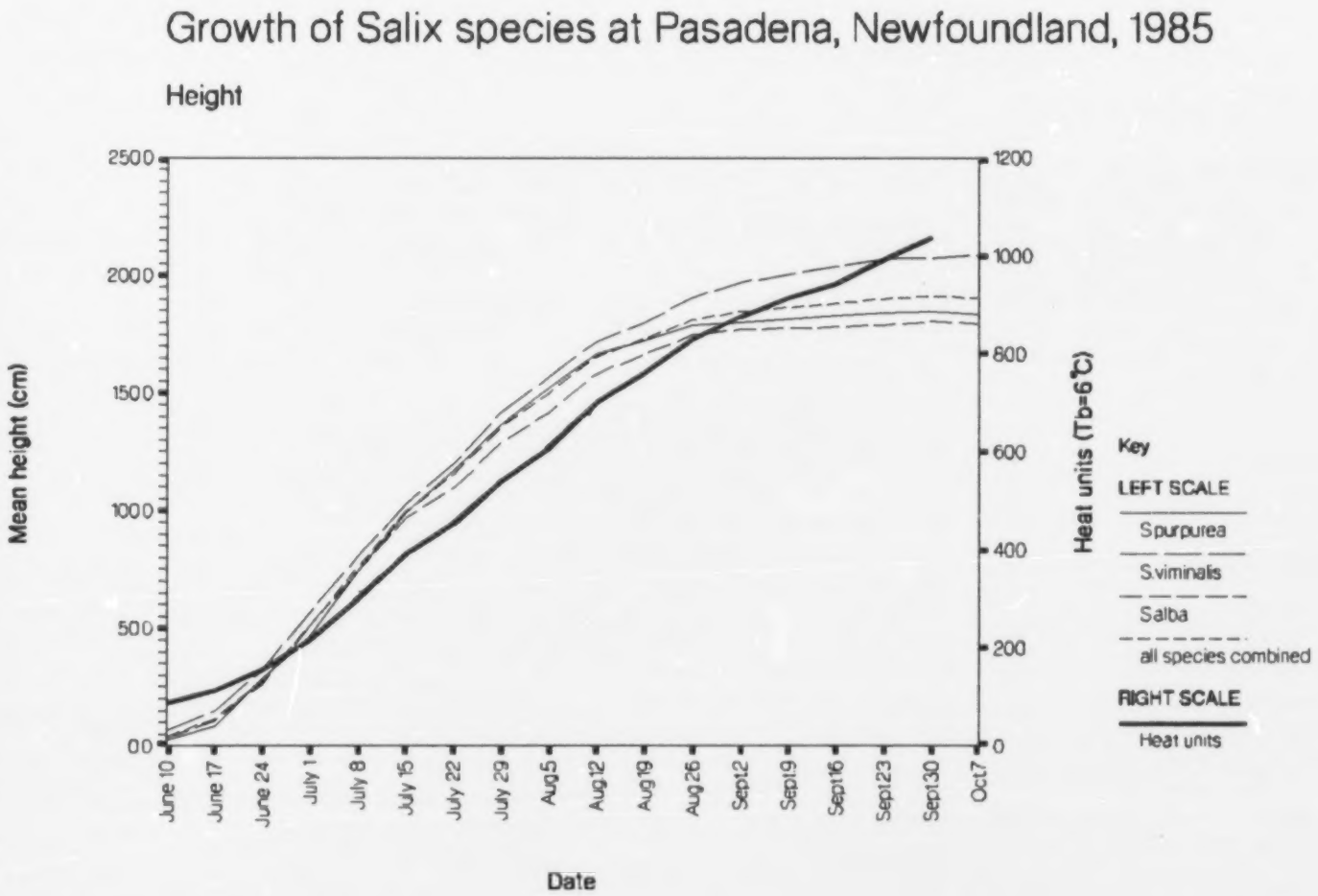

Figure 6. Growth of Salix species at Pasadena, Newfoundland, 1985 Height.

S. purpurea and S. alba attained final mean heights of 183.5 cm ($S_{\bar{x}}$ = 6.0 cm) and 179.5 cm ($S_{\bar{x}}$ = 4.0 cm) respectively. All three species had reached approximately 80% of their final height by August 5, indicating that a majority of the height growth occurred during the months of June and July. Cumulative heat units increased rapidly after June 24 and showed a steady increase until the end of August. S. viminalis experienced greater shoot elongation in the latter part of the growing season as compared to the other species and this appears to have contributed to its increased final height attainment. Figure 7 displays S. viminalis clones at the end of the growing season.

Figure 8 displays the seasonal growth pattern of the mean basal diameter for each of the three species examined as well as cumulative heat units for the growing season. S. viminalis attained the greatest basal diameter by the end of the growing season ($\bar{x}$ = 1.49 cm, $S_{\bar{x}}$ = 0.03 cm) and S. alba showed similar dimensions ($\bar{x}$ = 1.44 cm, $S_{\bar{x}}$ = 0.05 cm). S. purpurea attained a final mean basal diameter of only 1.07 cm ($S_{\bar{x}}$ = 0.03 cm). The rate of growth of basal diameter began to decrease after August 5, with over 80% of the whole season's growth taking place prior to this date. S. viminalis and S. alba both experienced a marked increase in basal diameter between August 26 and September 2 with S. viminalis continuing this increased rate of growth until the week of September 16. S. purpurea and S. viminalis experienced a slight reduction in basal diameter between September 16 and 23.

Figure 7. Salix viminalis clones at the end of the growing season.

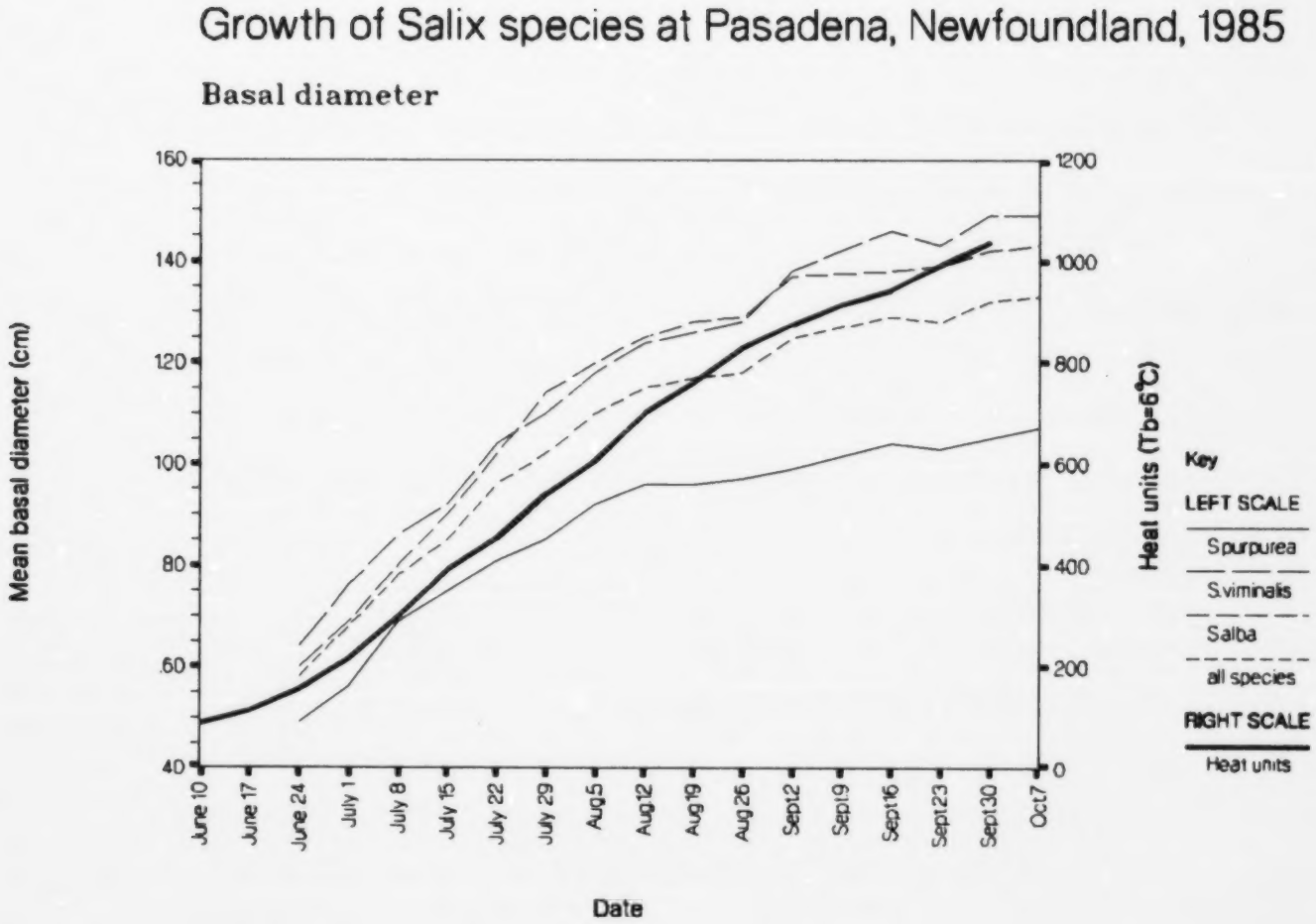

Figure 8. Growth of Salix species at Pasadena, Newfoundland 1985 Basal diameter.

4.2 Meteorological Variables

Hourly mean windspeed is displayed in Figure 9. Maximum weekly mean windspeed occurred during the week of July 23 to 29, when its value was 1.0 m/sec. Weekly mean windspeed rarely exceeded 0.5 m/sec. and was relatively constant throughout the growing season.

Figure 10 displays the weekly mean of the maximum air temperature observed daily at the study site. A minimum value of 14°C occurred twice during the observation period, during the weeks of June 11 to 17 and September 10 to 16 and a maximum value of 27.5°C was observed during the week of August 6 to 12. Weekly mean maximum air temperature increased rapid from the start of observations on June 11 until the end of the first week in July. During the weeks from July 9 to August 19 some variation in mean maximum temperature occurred and then a steady, downward trend was experienced for the remainder of the observation period. A brief increase in mean maximum air temperature occurred during the week of September 17 to 23.

Weekly mean air temperature was calculated from daily mean values recorded at the Atmospheric Environment Service's meteorological station at Deer Lake, Newfoundland. The results are shown in Figure 11. Weekly mean air temperature followed the same pattern as weekly mean maximum air temperature, with a maximum value of 19.5°C occurring during the week of August 6 to 12. Weekly mean air temperature increased rapidly from June 17 until July 8 and then experienced some variation between July 9 and August 19. A steady decrease in weekly mean air

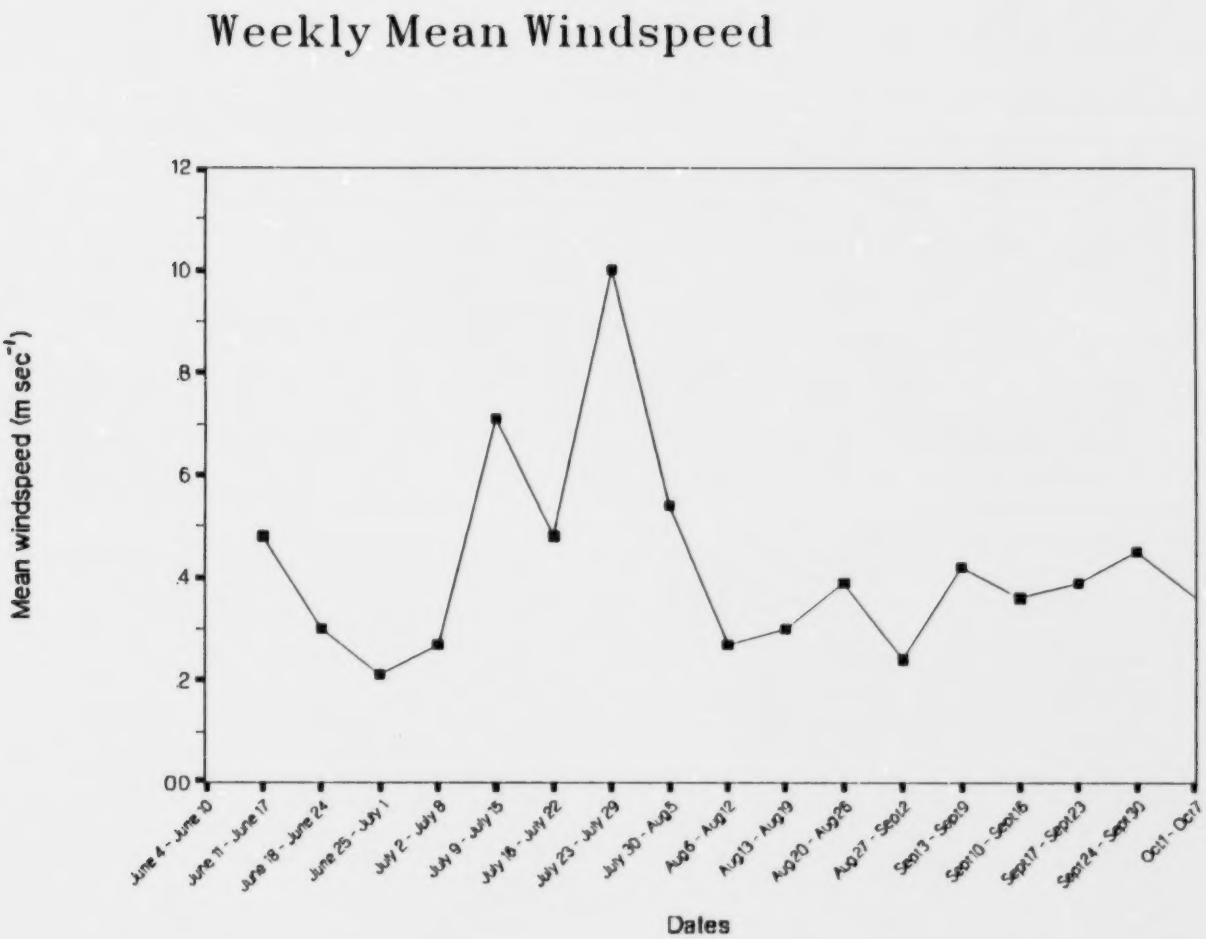

Figure 9. Weekly mean windspeed.

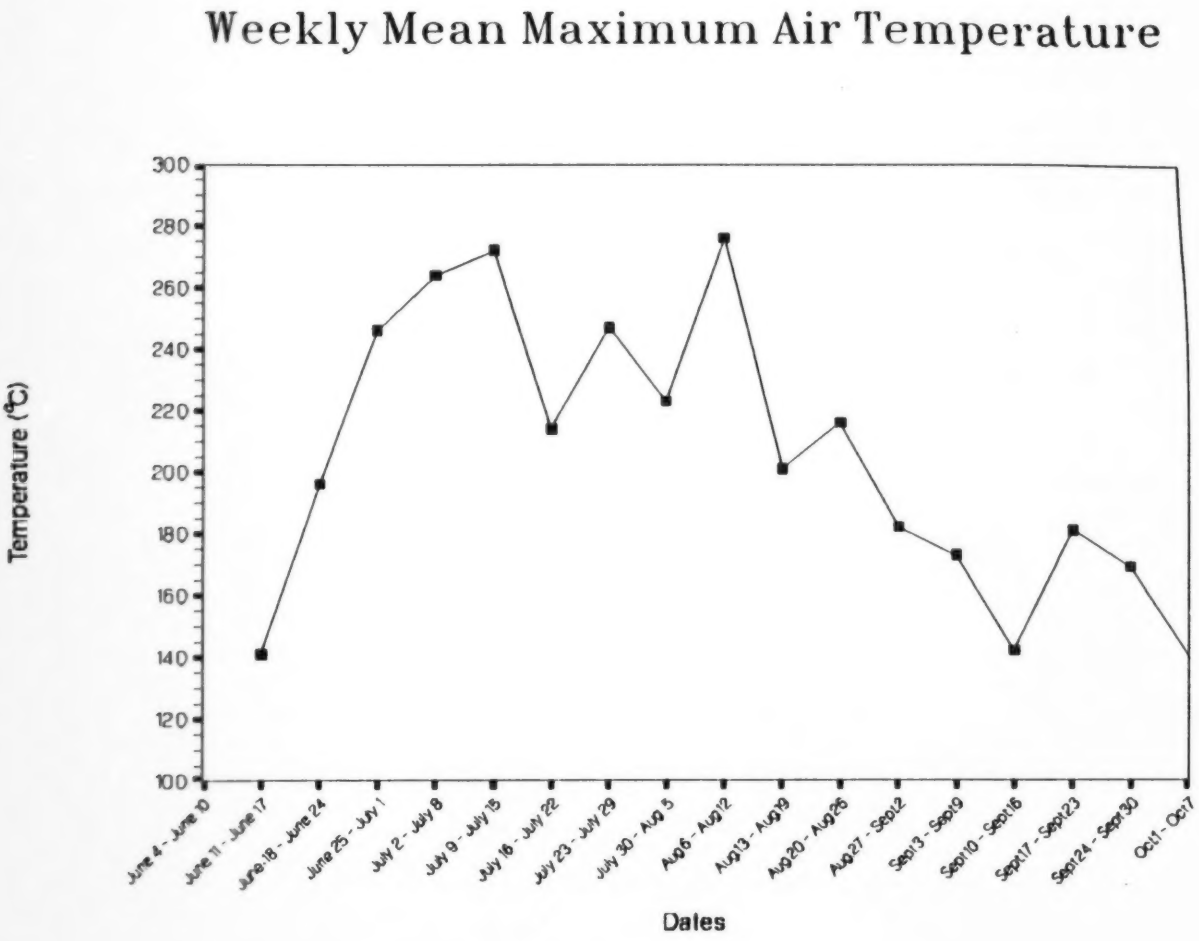

Figure 10. Weekly mean maximum air temperature.

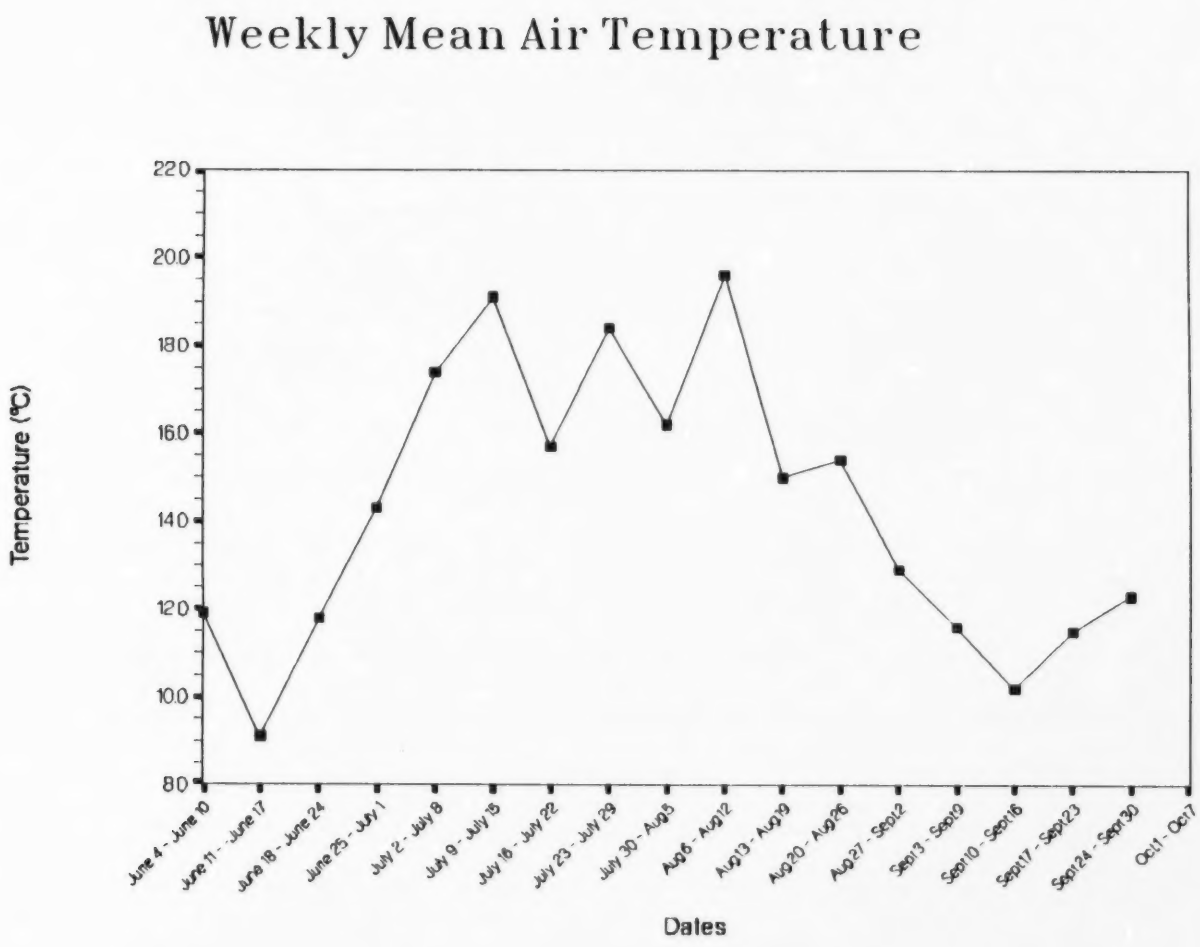

Figure 11. Weekly mean air temperature.

temperature occurred between August 20 and September 16 and a slight increase occurred toward the end of the observation period.

Figure 12 displays the weekly mean soil temperatures at 10, 20 and 30 cm below the surface as calculated from daily average temperatures recorded at 14:00 NDST. Weekly mean soil temperature at all depths showed a rapid increase from June 18 until the week of July 2 to 8 when maximum temperatures at all three depths occurred. Soil temperature followed a similar pattern to that of weekly mean measurements of air temperature, with weekly mean soil temperatures fluctuating moderately between July 9 and August 19.

Weekly total precipitation recorded at the study site is displayed in Figure 13. Maximum total weekly precipitation occurred during the week of July 16 to 22 when 40.0 mm of rain was recorded. Less than 4.0 mm of precipitation fell during the weeks of July 9 to 15, July 23 to 29, August 6 to 12 and September 24-30. For the three weeks between August 27 and September 16, a steady, even distribution of rainfall occurred totalling 65.0 mm.

Weekly mean relative humidity was calculated from daily readings of the wet and dry bulb thermometers at 14:00 NDST and converted to percent relative humidity values via psychometric tables (Environment Canada, 1976). The results are shown in Figure 14. A minimum value of 50% R.H. occurred during the week of June 25 to July 1 and a maximum value of 80% occurred during the week of July 16 to 22, also the week that maximum total precipitation was recorded. Relatively low values of 59% and 58% R.H. were recorded during the weeks of July 9 to 15 and

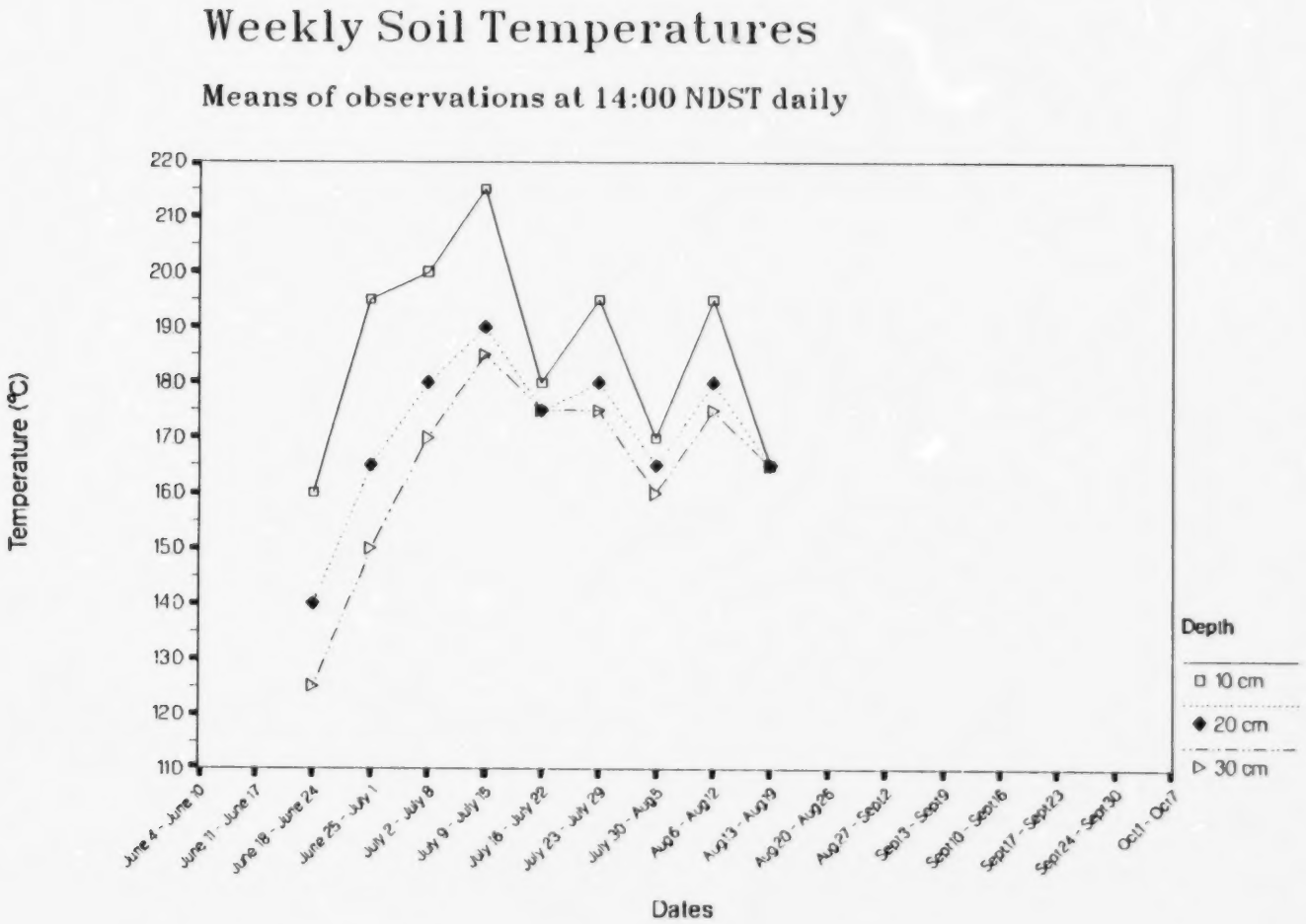

Figure 12. Weekly soil temperatures.

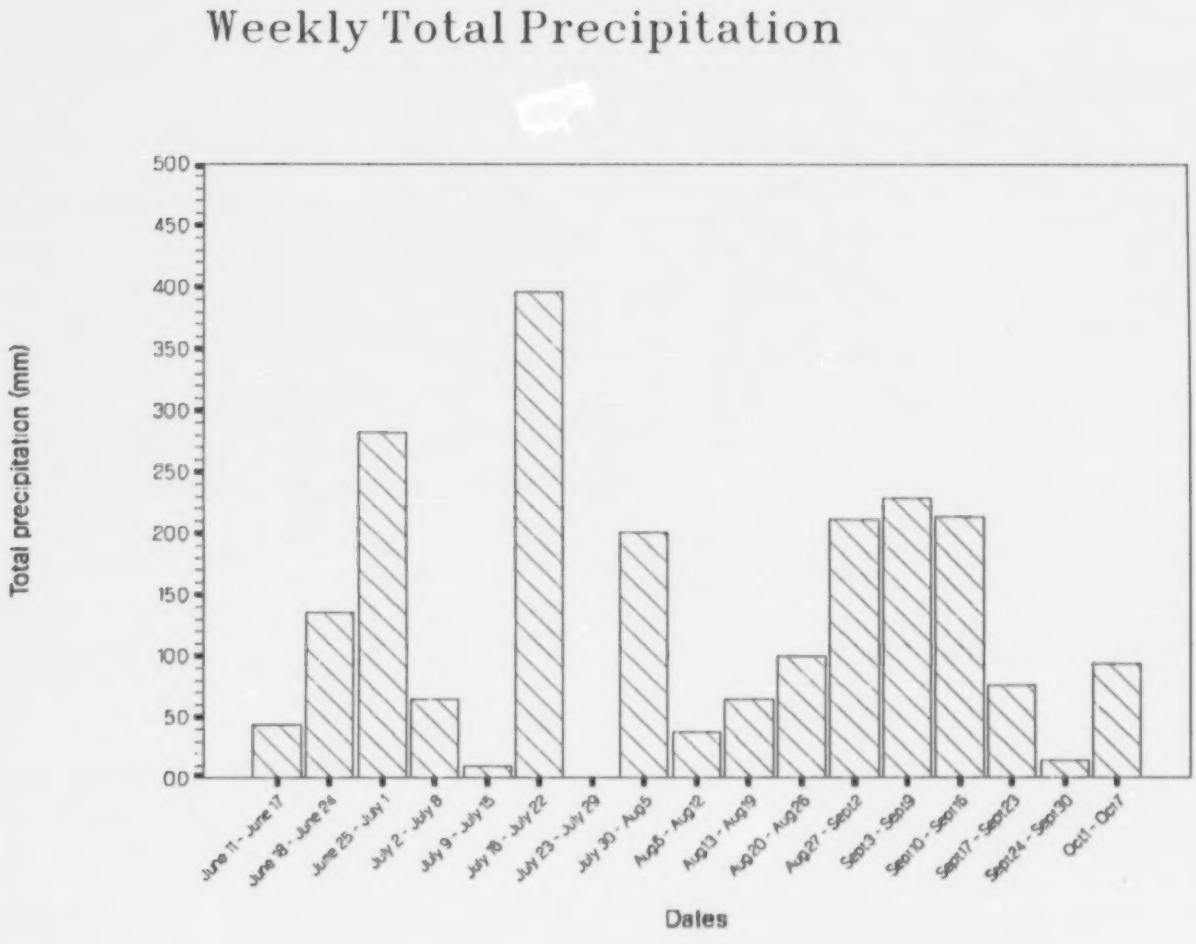

Figure 13. Weekly total precipitation.

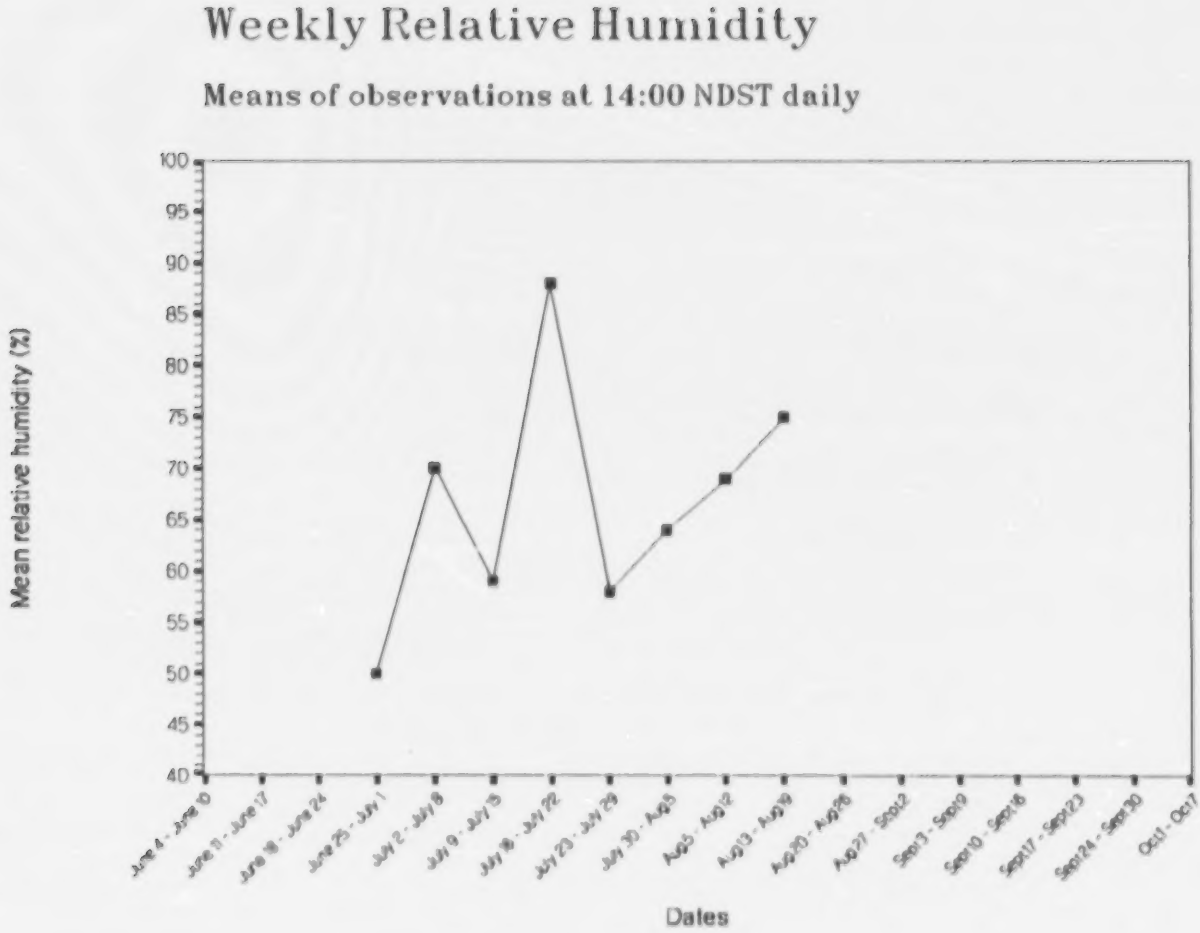

Figure 14. Weekly relative humidity.

July 23 to 29, weeks with total precipitation of 1.0 mm and 0.0 mm respectively. Weekly relative humidity increased steadily from July 29 to August 19.

4.3 Daily Growth Patterns

Figure 15 displays the mean daily height increment change between June 20 and August 17 for all three species of Salix studied at Pasadena in 1985. The willow species examined averaged a height increase of 0.07 cm between the hours of 22:00 and 06:00 and between the hours of 06:00 and 14:00. The trees experienced a significantly greater increase in height between the hours of 14:00 and 22:00 as compared to within the other two time intervals $\left(p(t_{v = 78.8} = 5.29) < .0001,\right.$

$\left. p\ (t_{v = 91.5} = -4.34) < .0001\right)$.

The mean daily basal diameter increment change between June 20 and August 17 is shown in Figure 16. Basal diameter increased an average of 0.02 cm between 22:00 and 06:00, decreased 0.01 cm between 06:00 and 14:00 and increased an average of 0.01 cm during the late afternoon and evening $\left(p(t_{v = 89.9} = -5.25) < .001\right)$.

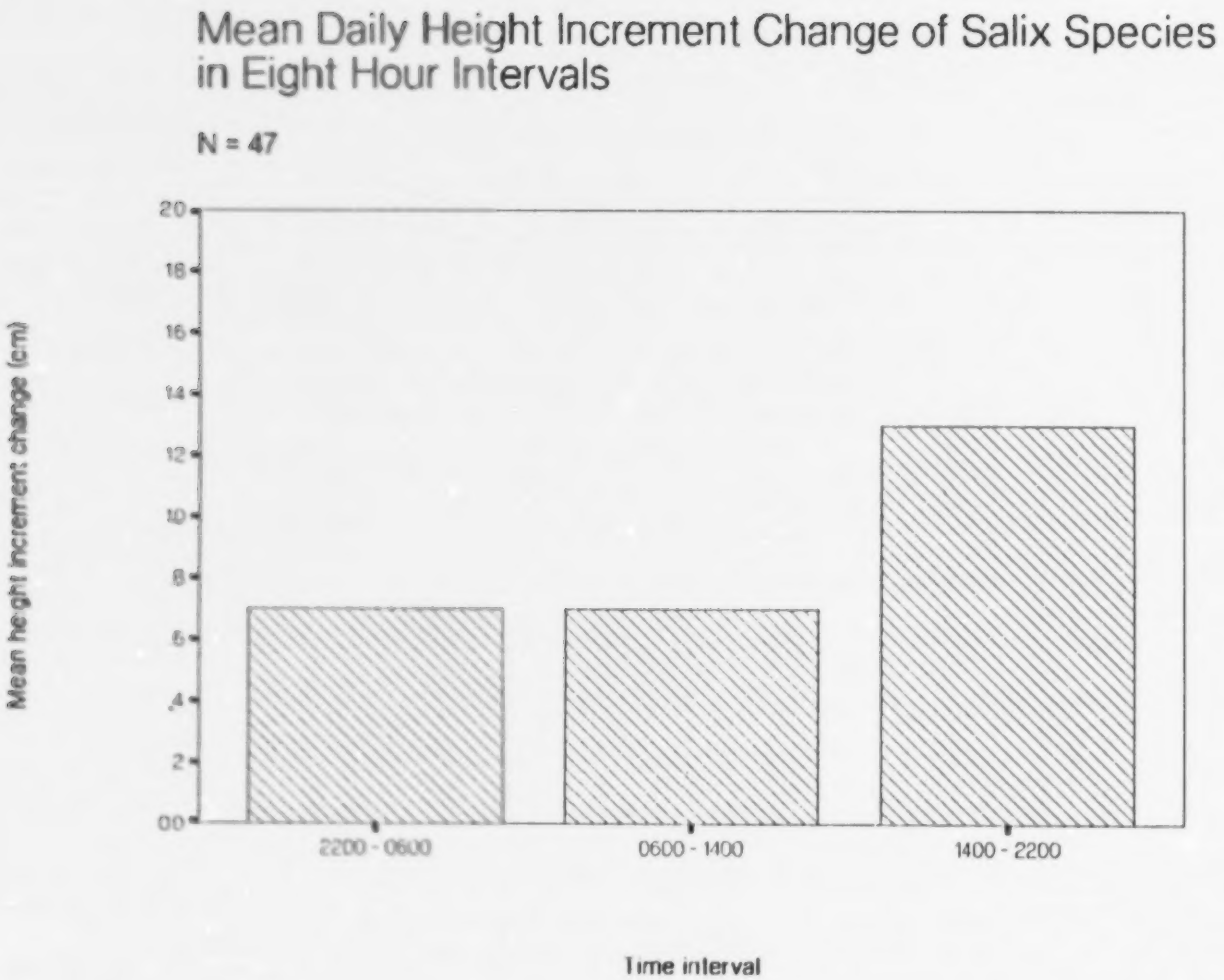

Figure 15. Mean daily height increment change of Salix species in eight hour intervals.

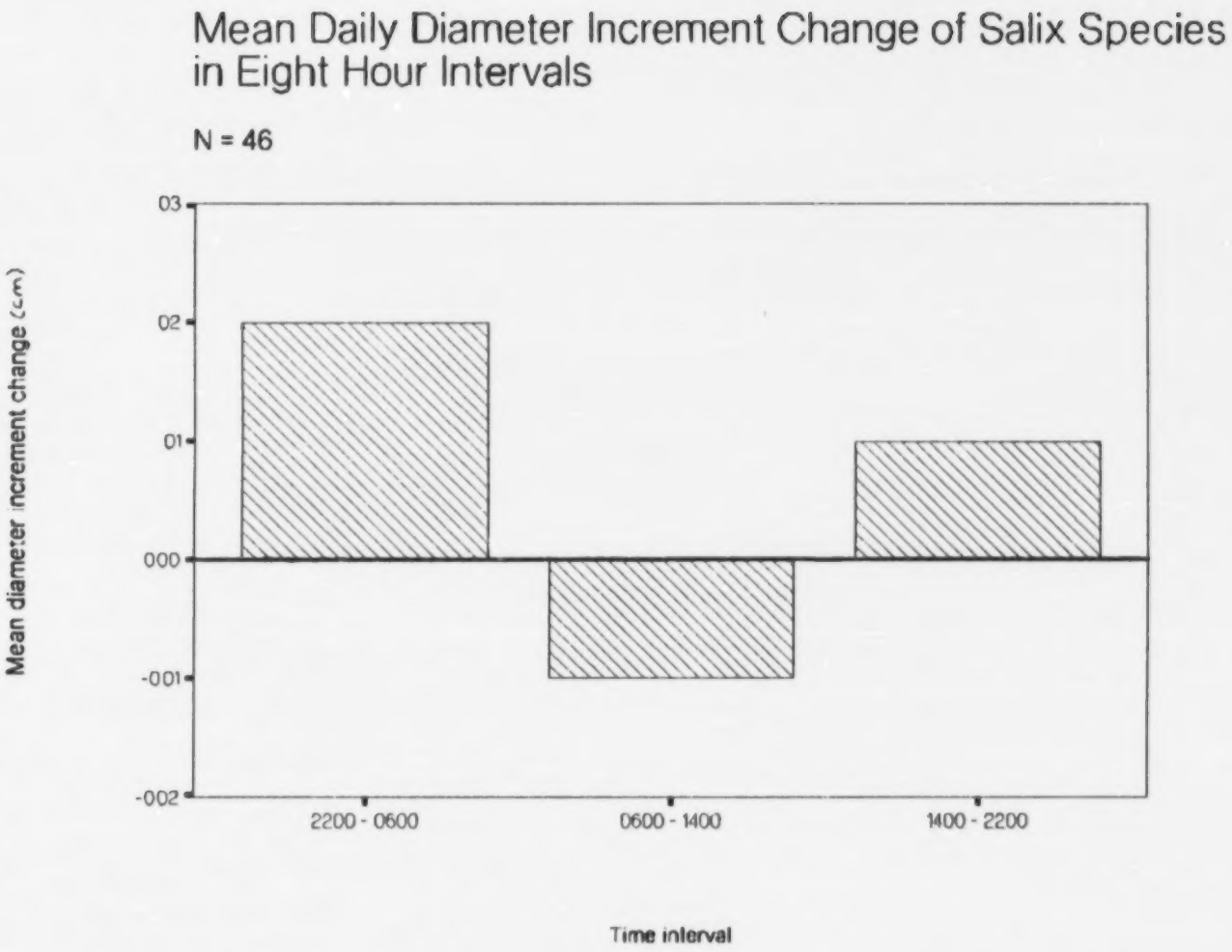

Figure 16. **Mean daily diameter increment change of <u>Salix</u> species in eight hour intervals.**

5.0 DISCUSSION AND CONCLUSIONS

The monitoring of seasonal growth of the three Salix clones during 1985 proved S. viminalis to be the most vigorous of the three species. It seems apparent that its superior performance is at least partly due to the clone's ability to continue shoot elongation later in the growing season while S. alba and S. purpurea showed little increase in total mean height after August 26. Calculated cumulative heat units appear to follow similar pattern of increase throughout the growing season. Measures of air temperature show a steady decrease in mean weekly values during this period of continued growth and total precipitation was steady and ample.

S. viminalis also achieved the greatest mean basal diameter by the end of the growing season. The marked increase in mean basal diameter of S. vinimalis and S. alba between August 26 and September 2 would appear to be the result of 20.0 mm of rain falling during this week after a total of only 20.0 mm had fallen over the three weeks previous to these dates. Calculated cumulative heat units again appear to increase steadily throughout the growing season in a similar pattern to the mean basal diameter growth. Mean air temperature was comparatively low during the week of August 26 to September 2, when the marked increase in basal diameter occurred. The decrease in basal diameter between September 16 and 23 is difficult to explain at this stage of data analysis since air temperature does not show any marked decrease and there is only a slight reduction in rainfall from previous weeks.

Small changes in temperature may affect photosynthesis, hormone synthesis, respiration, transpiration, chlorophyll synthesis, enzymatic activity and cell division (Kramer and Kozlowski, 1960). Plant growth is affected by bud formation, bud dormancy, initiation and seasonal distribution of bud expansion into a shoot, all of which are temperature dependent. The temperature extremes for photosynthesis are -5°C to 35 to 40°C (Kozlowski and Keller, 1966). Species vary widely in their optimal temperature for maximum photosynthetic rate, but it usually ranges from 18 to 25°C depending on light intensity (Kruger and Farrell, 1965; Brix, 1967; Larcher, 1969). Toumey and Korstian (1947) found that if the mean air temperature of the four hottest months of the growing season falls below 10°C tree growth is seriously reduced. Low air and soil temperatures are thought to reduce water absorption by the plant, which in turn inhibits growth (Bowman, 1911; Handley, 1939, Fries, 1943).

The effect of soil water on plant growth depends on current soil moisture status, soil texture and moisture release characteristics, extent and concentration of absorbing rootlets and the rate of water movement through the soil (Winter, 1968). This study, unfortunately, made no direct measures of soil moisture status which is well documented as having an important environmental effect on seasonal growth of forest trees (Kramer and Kozlowski, 1960; Kozlowski, 1964). Kramer and Kozlowski (1979) point out that 95% of the water that is taken up by a plant passes through the plant and is lost via transpiration. Gates (1965) cites the positive effects of transpiration as being the cooling

of leaves, ascent of sap and increase absorption and translocation of minerals. However, on very sunny days, transpiration tends to increase, resulting in the rapid loss of water from young twigs and leaves, and the stomata close reducing photsynthesis. This may result in reduction of ceasing of growth (Kramer and Kozlowski, 1979).

The values of mean weekly windspeed were likely too low to have any noticeable effect on the seasonal growth pattern of Salix species at Pasadena. Wind acts to mix the air surrounding a plant, supplying fresh carbon dioxide and taking away heat and water vapour (Grace, 1981). Increased winspeed can lead to increased transpiration and hence, may cause water stress. The evaporation rate is increased due to the effect of wind decreasing the boundary layer resistance around the plant (ibid).

Height growth during the late afternoon and early evening (14:00-22:00) of the three species of Salix studied proved to be almost twice that which took place during the other two eight hour intervals. Fielding (1955) found a similar pattern when examining the daily terminal elongation of Pinus radiata in Australia, where the fastest growth rate occurred between 15:00 and 24:00. This pattern is likely a result of transpirational rates being lower at this time of day. When a tree is under transpirational stress, it is unable to form assimilates and growth is reduced. High temperatures would be assumed to enhance growth in temperate climates, except that they often occur on days with low humidity and therefore should contribute to moisture stress and reduced growth.

A similar explanation can account for the daily pattern of basal diameter increment change found to exist between June 20 and August 17. Similar daily hydrostatic changes in stem thickness of forest trees are well documented in the literature (Kramer and Kozlowski, 1960). It is reputed to be regulated by soil water content and transpirational rates. This daily pattern of height and diameter growth will therefore be affected by those climatic variables which regulate transpiration rates and will be examined in further analysis of the data.

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